BIOLOGICAL EFFECTS OF IONIZING RADIATION

Refer to the reading entitled *Biological Effects of Ionizing Radiation* to answer the questions below.

1. The principle factors that determine the biological effect of ionizing radiation are ______________ *(radiation dose, type of radiation, type and volume of biological cells exposed)*

2. The possibility of injury from ionizing radiation *(increases)* with increasing exposure.

3. Increasing the volume of tissue exposed *(increases)* the severity of radiation injury.

4. Alpha particles deposit all their energy in a *(short)* path.

5. X-rays and gamma rays deposit their energy over a *(longer)* path.

6. The two main categories of biological effects are *(somatic)* effects and *(genetic)* effects.

7. Of the two main types of effects in question 6, which applies to the exposed individual and which applies to future generations?

   (somatic) effects apply to the exposed individual

   (genetic) effects apply to future generations

8. Background radiation accounts for only *(1)* to *(3)* percent of the spontaneous incidence of cancer.

9. The *(unborn)* and *(newborn)* are particularly sensitive to radiation exposure.

10. For any radiation exposure greater than zero, there is some *(risk)* .

USING HALF-LIVES

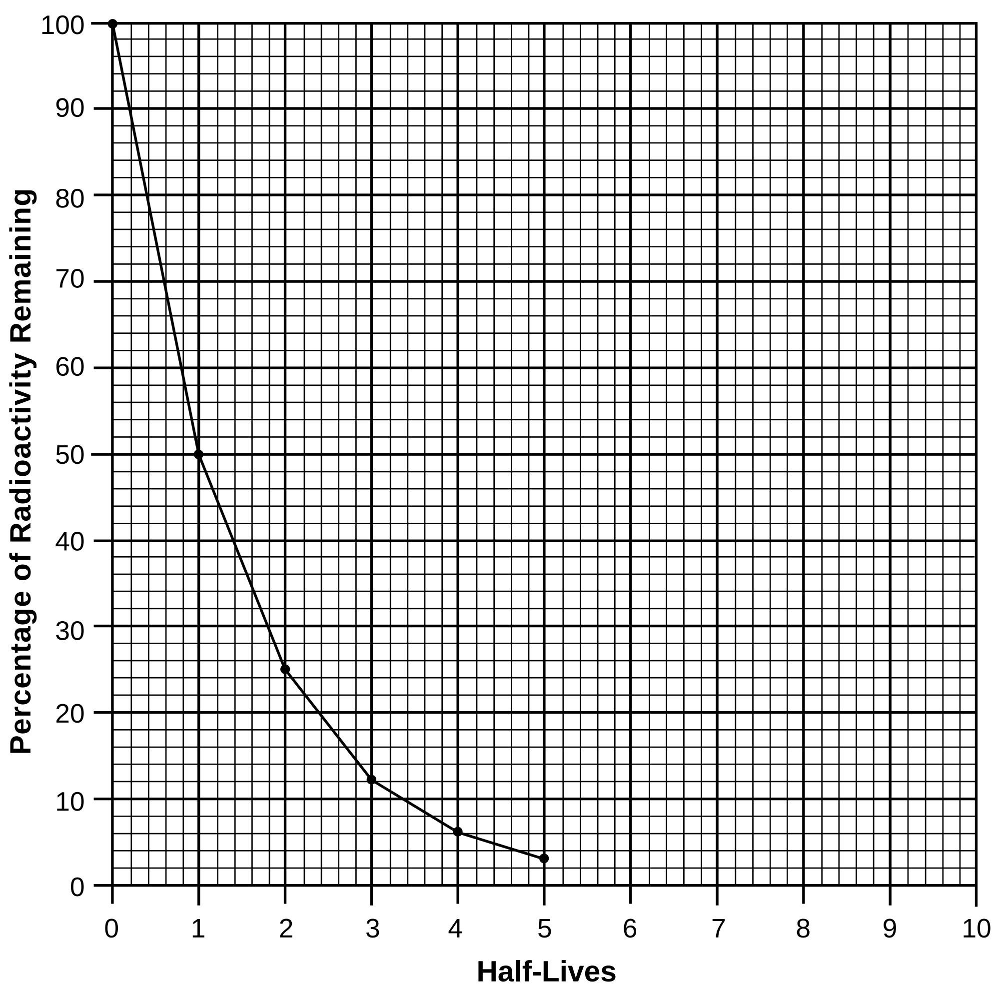
Radioactive materials spontaneously emit ionizing radiation during the process of radioactive decay and become less radioactive over time as a result of this process. The time required for a quantity of a radioactive substance to lose half its radioactivity by radioactive decay is the half-life of that substance. Half-life is a unique characteristic of each radioisotope.

Directions: Answer the following questions by applying the information about half-life given above. Read carefully and think before answering.

1. What percentage of the original radioactivity of a quantity of a radioactive material remains after each half-life?

0	1	2	3	4	5
100%	*50%*	*25%*	*12.5%*	*6.25%*	*3.125%*

2. Plot the radioactive decay curve from data in Question 1. On the x-axis plot half-lives and on the y-axis the percentage of radioactivity remaining. Connect each point with straight line segments.



3. Radium has a half-life of 1600 years. Approximately, how long does it take for 1 percent of a sample of radium to decay?

Method 1

{If 50% decays in 1600 years then 1% decays in how many years?}

$$\frac{50\%}{1600 \text{ years}} = \frac{1\%}{x \text{ years}} \qquad \text{(set up a proportion)}$$

$$(50\%)\,(x \text{ years}) = (1\%)\,(1600 \text{ years}) \qquad \text{(cross multiply)}$$

$$\frac{(50\%)\ (x \text{ years})}{50\%} = \frac{(1\%)\ (1600 \text{ years})}{50\%} \qquad \text{(solve for x)}$$

$$x = 32 \text{ years}$$

Method 2

$$\frac{1}{50}\,(1600) = 32 \text{ years}$$

4. Radon has a half-life of 3.8 days. Approximately, how long does it take for 1 percent of a sample of radon to decay? Express your answer in hours.

Method 1

$$\frac{50\%}{3.8 \text{ days}} = \frac{1\%}{x \text{ days}}$$

$$\frac{(50\%)\ (x \text{ days})}{50\%} = \frac{(1\%)\ (3.8 \text{ days})}{50\%}$$

$$x = 0.076 \text{ days}$$

$$\frac{1 \text{ day}}{24 \text{ hours}} = \frac{0.076 \text{ days}}{x \text{ hours}}$$

$$\frac{(1 \text{ day})\ (x \text{ hours})}{1 \text{ day}} = \frac{(0.076 \text{ days})(24 \text{ hours})}{1 \text{ day}}$$

$$x = 1.82 \text{ hours}$$

Method 2

$$\frac{1}{50}\,(3.8)\,(24) = 1.82 \text{ hours}$$

5. Scientists believe the Earth is 4.6 billion years old

   a. Approximately what percentage of the uranium-238 originally present is here now if the half-life of uranium-238 is 4.5 billion years?

   approximately 50%

   b. Calculate a more exact percentage.

   Number of half-lives elapsed (H) = $\frac{\text{Elapsed Time}}{\text{Half - Life}}$

   $$H = \frac{4.6 \text{ billion years}}{4.5 \text{ billion years}}$$

   $$H = 1.022$$

This represents one half-life plus 0.022 of the second half-life. After 1 half-life, 50% has decayed and 50% remains. Remember that after 2 half-lives, 25% of the original radioactivity remains. The answer is between 50% and 25%. Calculate on the 50% remaining after one half-life.

Method 1

$$\frac{25\% \text{ will decay}}{1 \text{ half-life}} = \frac{x\% \text{ will decay}}{0.022 \text{ half-lives}}$$

$$\frac{(25\%)(0.022 \text{ half-lives})}{1 \text{ half-life}} = \frac{(x\%)(1 \text{ half-life})}{1 \text{ half-life}}$$

$$0.55\% = x$$

$$50\% - .55\% = 49.45\% \text{ remaining}$$

Method 2

Percent left after 1.022 half-lives

$$50\% - (0.022)(25\%) = 49.45\%$$

6. Calculate approximately what percent of the original thorium-232 is left if it has a half-life of 14 billion years.

Method 1

$$H = \frac{4.6 \text{ billion years}}{14 \text{ billion years}} = 0.329 \text{ half-lives (one half-life has not been completed)}$$

In the first completed half-life 50% of the original amount of thorium-232 will decay.

$$\frac{50\%}{1 \text{ half-life}} = \frac{x\%}{0.329 \text{ half-lives}}$$

$$\frac{(50\%)(0.329 \text{ half-lives})}{1 \text{ half-life}} = \frac{(x\%)(1 \text{ half-life})}{1 \text{ half-life}}$$

$$16.45\% = x$$

$$100\% - 16.45\% = 83.55\% \text{ remaining}$$

Method 2

$$\text{Number of half-lives} = \frac{4.6}{14} = 0.329$$

$$100\% - (0.329 \times 50\%) = 83.55\%$$

7. Uranium-235 has a half-life of 0.7 billion years and also was present when the Earth was formed.

a. How many U-235 half-lives have occurred since the beginning of the Earth?

$$H = \frac{4.6 \text{ billion years}}{0.7 \text{ billion years}}$$

$$H = 6.57 \text{ half-lives}$$

b. Approximately what percent of the original uranium-235 is left?
(Hint: Make a table of half-lives and calculate the fraction remaining after each half-life.)

Half-lives	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Fraction Remaining	*1/2*	*1/4*	*1/8*	*1/16*	*1/32*	*1/64*	*1/128*

By the sixth half-life 1/64th or 2/128th of the original U-235 remains.
In this problem 0.57 of those 2/128ths will decay.

$$\frac{2}{128} - \frac{.57}{128} = \frac{1.43}{128}$$

$$\frac{1.43}{128} = \frac{x}{100} \quad \text{(Change to a percent.)}$$

$$\frac{(1.43)(100)}{128} = \frac{(128)(x)}{128}$$

$$1.12\% = x$$

This problem can also be answered using percentages.

Half Lives	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Percentage Remaining	*50%*	*25%*	*12.5%*	*6.25%*	*3.13%*	*1.56%*	*0.78%*

By the sixth half-life 1.56% of the original U-235 remains. During the sixth half-life 0.78% of the original amount will decay.

$$\frac{0.78\%}{1 \text{ half-life}} = \frac{x\%}{0.57 \text{ half-lives}}$$

$$\frac{(0.78\%)(0.57 \text{ half-lives})}{1 \text{ half-life}} = \frac{(1 \text{ half-life})(x\%)}{1 \text{ half-life}}$$

$$0.44\% = x$$

$$1.56\% - 0.44\% = 1.12\%$$

8. All natural uranium contains both U-235 and U-238. Each decays at a different rate but both are always present in any quantity of natural uranium. We must consider changes in both U-235 and U-238 to calculate the concentration of either at any given time. Keep in mind that natural uranium = U-235 + U-238.

   a. Today, natural uranium contains about 0.7% U-235. How much U-238 does natural uranium contain today?

$$\underset{\text{(Nat. U)}}{100\%} - \underset{\text{(U-235)}}{0.7\%} = \underset{\text{(U-238)}}{99.3\%}$$

   b. The percentages from (a.) are true for any unit of natural uranium. Consider one gram of natural uranium today. What fractional portion of U-235 and of U-238 would comprise that one gram of natural uranium?

   (The choice of one gram as a measure of mass is completely arbitrary. Any mass—one pound, two ounces, etc.—would produce the same answer.)

$$\text{U-235} \quad \frac{0.7\%}{100\%} = \frac{x \text{ grams}}{1 \text{ gram}}$$

0.007 grams = x

U-238 $\frac{99.3\%}{100\%} = \frac{x \text{ grams}}{1 \text{ gram}}$

0.993 grams = x

c. How much U-235 was required 4.6 billion years ago to produce 0.007 grams of U-235 in every gram of natural uranium today? Remember that 1.1% of the total amount of U-235 remains undecayed today. (Question 7b)

$$\frac{0.007 \text{ grams U-235 today}}{1.1\% \text{ of original amount}} = \frac{x \text{ grams U-235 4.6 billion years ago}}{100\% \text{ of original amount}}$$

0.636 grams U-235 = x

d. How much U-238 was required 4.6 billion years ago to produce 0.993 grams of U-2238 in every gram of natural uranium today? Remember that 49.45% of the total amount of U-238 remains undecayed today. (Question 5b)

$$\frac{0.993 \text{ grams U-238 today}}{49.45\% \text{ of original amount}} = \frac{x \text{ grams U-238 4.6 billion years ago}}{100\% \text{ of original amount}}$$

2.008 grams U-238 = x

e. Keeping in mind that natural uranium = U-235 + U-238, what percent of U-235 existed in natural uranium 4.6 billion years ago?

$$\frac{0.636 \text{ grams U-235}}{0.636 \text{ grams U-235} + 2.008 \text{ grams U-238 (natural uranium)}} = \frac{x\%}{100\%}$$

24.05% = x

9. Based on evidence discovered in 1972, scientists believe that about 2.0 billion years ago, a fission chain reaction occurred spontaneously at Oklo, Gabon, in Africa. Remember that natural uranium = U-235 + U-238 and that U-235 at some concentration was necessary for this reaction to occur. Answer the following to determine the concentration of U-235 in natural uranium 2.0 billion years ago.

a. How much time had elapsed since the formation of the Earth 4.6 billion years ago when the reaction at Oklo occurred?

4.6 billion years - 2.0 billion years = 2.6 billion years

b. At the time of the Oklo reaction, how many half-lives of U-235 and of U-238 had elapsed?

$$H\ U\text{-}235 = \frac{2.6}{0.7} = 3.71 \text{ elapsed}$$

$$H\ U\text{-}238 = \frac{2.6}{4.5} = 0.58 \text{ elapsed}$$

c. What percentage of the original amount of U-235 and U-238 remained at the time of the nuclear reaction in Oklo, Gabon?

U-235 - By the third half-life 1/8th or 2/16ths of the original U-235 remains. In this problem 0.71 of those 2/16ths will decay.

$$\frac{2}{16} - \frac{0.71}{16} = \frac{1.29}{16} = 0.08 \qquad 0.08 \times 100 = 8\%$$

U-238- At the beginning of the first half-life 1/1 or 2/2 of the original U-238 remains. In this problem 0.58 of those 2/2 will decay.

$$\frac{2}{2} - \frac{0.58}{2} = \frac{1.42}{2} = 0.71 \qquad 0.71 \times 100 = 71\%$$

d. 4.6 billion years ago natural uranium was 24.05% U-235. (Question 8). What percent of natural uranium was U-238?

100% - 24.05% = 75.95%
(Natural Uranium) (U-238)

e. Consider one gram of natural uranium 4.6 billion years ago. What fractional portion of U-235 and U-238 would comprise that one gram?

$$U\text{-}235 \qquad \frac{24.05\%}{100\%} = \frac{x\ g}{1g}$$

0.2405 grams U-235 = x

$$U\text{-}238 \qquad \frac{75.95\%}{100\%} = \frac{x\ g}{1g}$$

0.7595 grams U-238 = x

f. If the one gram of natural uranium from (e.) were to decay until the time of the Oklo reaction, how many grams of U-235 and U-238 would remain?

U-235 - $$\frac{0.2405 \text{ grams U-235}}{100\%} = \frac{x \text{ grams U-235}}{8\%}$$

0.019 grams U-235 = x

U-238 $$\frac{0.7595 \text{ grams U-238}}{100\%} = \frac{x \text{ grams U-238}}{71\%}$$

0.539 grams U-238 = x

g. Keeping in mind that natural uranium = U-235 + U-238, what percent of U-235 existed in natural uranium at the time of the Oklo reaction?

$$\frac{0.019 \text{ grams U-235}}{(0.539 \text{ grams U-238} + 0.019 \text{ grams U-235})} = \frac{x\%}{100}$$

3.4% = x

Note: Fuel used in nuclear powerplants in the United States is approximately 3-4% uranium-235.

The Oklo reactor consumed about 6 tons of U-235 over hundreds of thousands of years. A large light water reactor (LWR) powerplant (1000 megawatts electric) consumes about one ton of U-235 every year.